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Effects of seasonal illumination and thermal environments on sleep in elderly men

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A B S T R A C T

The purpose of this study was to investigate the effect of changes in the seasonal thermal environment and illuminance on sleep in older men by using actigraphy. Eight healthy male volunteers with a mean age of 64 ± 1 years served as subjects. The measurements were obtained in 4 consecutive seasons: spring, summer, autumn, and winter. The activity level and illuminance were monitored using a wrist actigraph system with illuminance meter for 5 consecutive days. Sleep parameters were determined using an actigraph-based, sleep-wake identification algorithm. The temperature and humidity in the bedroom of the subjects' homes were measured continuously for 5 days. During the actigraphic measurement, skin temperature and the temperature and humidity of the microclimate were measured continuously for 2 nights. Bedroom nocturnal Ta and humidity was significantly higher in the summer than in the other seasons. Sleep efficiency was worst in the summer due to the increased number and duration of nocturnal awakenings. However, a significant difference was not found in the subjective evaluation of sleep among the 4 seasons. The correlations between the sleep parameters and environmental factors such as temperature, humidity, and illuminance levels measured at the same time showed that increased lighting level before the sleep prolongs the bedtime and wake time after sleep onset, and became wake-up time earlier. Increased ta, humidity, and lighting level during the sleep period mount up the wake time after sleep onset and impaired the sleep efficiency index.

1. Introduction

Lighting plays an important role in the daily and seasonal rhythms of human life. Sleep is regulated by two systems: sleep/wake homeostasis and the circadian biological clock. Both circadian rhythm and sleep quality are influenced by light (the photoperiod) via neuroendocrine hormones. Sleep is also strongly linked to human thermoregulation, with the thermal environment being a key determinant of sleep.

Seasonal variations affect sleep quality, with decreased sleep stage 4 and increased rapid eye movement sleep (REM) occurring under the thermoneutral conditions present in winter compared to summer in Hokkaido (43° 39′N) [1]. Stage 4 sleep is the second stage of deep sleep, in which the brain is making the slow delta waves almost exclusively and REM sleep in which dreams generally occur. In subtropical climates, REM sleep lasts longer and REM latency is reduced in winter and spring, than in summer and fall [2]. The seasonality of REM sleep patterns was replicated, but not confirmed, in the same geographical area [3]. These direct effects on sleep quality are difficult to explain based on photoperiod time cues [1], and suggest that the effects of air temperature (Ta) cause seasonal variation [2].

Complaints about difficult initiation and maintenance of sleep increase with age due to increased numbers of brief awakenings and decreased slow wave sleep (SWS) [4–6]. Age-related decreases in melatonin secretion among healthy, elderly people are often associated with various types of sleep problems. Elderly nursing home residents who suffer from insufficient environmental illumination show diminished melatonin secretion [7]. Increased light exposure during the daytime improves nocturnal melatonin secretion in these elderly insomniacs; however, sleep duration and quality has not been confirmed to improve with increased light exposure in elderly nursing home residents (average age, >70 years). Many older persons live independently, for years, before entering nursing homes. However, few studies have examined the effect of illumination on the sleep patterns of these older adults,

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living independently in their homes. When light exposure data were recorded for a week in older and young subjects living at home on self-selected sleep-wake schedules, and matched for the time of year, the older subjects show higher levels of light exposure than young subjects throughout their waking day [8]. In a cross-sectional study, daylight exposure was reported to be positively associated with urinary melatonin excretion among the elderly [9]. In Japan, the duration of the photoperiod, levels of illumination, and the thermal environment change because of changing seasons. The effects of the seasonal lighting environment on the sleep of healthy, elderly individuals are unclear. When the effects of season on sleep and skin temperature (Tsk) in healthy, elderly people were compared over 3 seasons, sleep was found to be more often disturbed, due to heat in summer than in autumn or winter [10]. However, the influence of lighting was not investigated in that study.

The present study aimed to investigate the ambient illuminance level for healthy elderly adults. This was measured by a wrist actigraph which was equipped with an on-board miniature photodiode, during the 4 seasons. The effects of illumination and thermal conditions on sleep among elderly persons during the 4 seasons were determined using the actigraphic measurements.

2. Methods

2.1. Subjects

The study participants were recruited from a pool of volunteers in the local human resource center, aged over 60 years, in the Tsukuba area of Japan (36°, 1′N). Based on their responses to a questionnaire, volunteers were excluded if they had chronic disease or insomnia, snored, took regular naps, required regular medication(s), had recently been hospitalized, or slept for extremely long or short times. Eight volunteers were selected for this study. They engaged in some simple work, i.e., gardening, cleaning, or office work, for 2 or 3 days a week. The subjects worked on a regular schedule in all seasons. The following physical characteristics (mean ± standard deviation) of the volunteers were measured: age (64 ± 1 years), height (162 ± 6 cm), weight (67 ± 8 kg), and body surface area (1.7 ± 0.1 m^2). The subjects were requested to lead their lives as normally as possible and to maintain a sleep log.

The volunteers were informed about the study protocol and each provided a written consent to participate. This study was approved by the ethics committee of Institute of Advanced Industrial Science and Technology (AIST). The subjects' physical and mental health was confirmed by their answers to a questionnaire regarding their physical and mental condition and sleep patterns, and whether each was a "morning (M) person" or an "evening (E) person" [11], prior to the start of the study. Seven of eight subjects were M type, and one was neither M type nor E type.

2.2. Procedure

The study was performed in the subjects' homes during four consecutive seasons: spring (from late April to early May), summer (from late July to early August), autumn (from late October to early November) and winter (from late January to early February); each subject participated in each seasonal measurement period.

The subjects were requested to wear two wrist actigraphy (Micro-mini motionlogger actigraph; Ambulatory Monitoring Inc., NY, USA and Actiwatch-L; Mini Mitter) on the nondominant hand for 5 consecutive days from Monday to Friday, except while bathing. Moreover, they kept a written sleep diary, to track bedtime, waking time, meal times, bathing time, and times when the actigraph was temporarily removed. Actigraphy is a physical activity monitor, typically worn on the wrist, to record activity movement level and intensity over time. An accelerometer generates a variable voltage that is digitally processed and sampled and a value expressed as activity counts is recorded in its board memory. The activity counts correlate with sleep/wake patterns. Actigraphic recordings were analyzed with commercial software (Action-W, 2.4.20, Ambulatory Monitoring Inc.) using the Cole-Kripke algorithm for scoring sleeping and waking [12]. Over the time course of the recordings, time in bed (TIB; defined as the primary sleep period during which subjects were trying to sleep in bed) was determined nightly according to the participants' sleep diary. Sleep latency (SL: time from bedtime to sleep onset), sleep period time (SPT: time from sleep onset to the end of last sleep episode in the morning), wake after sleep onset (WASO: total waking time scored in SPT), and sleep efficiency index (SEI: percentage of sleeping time in SPT) were calculated by the software. Another actiwatch-L was equipped with an on-board miniature photodiode for measurement of the amount and duration of illuminance. We used the actiwatch-L as a photometer, to measure the light intensity from 1 to 150,000 lux in an interval of 1 min. The subjects were asked to expose the actiwatch-L to the ambient environment, without covering it with their clothing.

During the activity-monitoring period, the outside temperature and the temperature and relative humidity (RH) of the bedroom in their own houses were measured continuously at 1-min intervals. During the nocturnal activity-monitoring period on Monday and Thursday, the Tsk of the forehead, chest, upper-arm, thigh, calf, and foot were continuously measured, also at 1-min intervals, using a thermistor and data logger (LT8A, Gram Corporation). The mean weighted Tsk was calculated according to the method of Ramanathan [13]. The microclimate temperature and humidity between the chest skin and pajamas were continuously measured, also at 1-min intervals, using a thermistor, hygrometer, and data logger (LA8B, Gram Corporation). A thermistor and a hygrometer probe were attached to a 5-mm-thick, 10 mm × 10 mm heatproof board, which was directly placed on the skin at the flat part of the upper chest area, under the pajama.

The bedding insulation was estimated by the investigators using the insulation values from a checklist, where the subjects answered about the number or kind of their bedding or covering used in the present study, because each insulation used by the subjects was hard to directly measure by a thermal manikin. The checklist included the insulation of many typical beddings or coverings that had been measured by a thermal manikin.

Thermal comfort questionnaire had to be filled out before and after sleep. Subjective evaluations for sleep were done using a questionnaire after sleep and responses to the questionnaire were obtained from each subject as follows: do you fall asleep easily? (1. well, 2. rather well, 3. neutral, 4. rather difficultly, 5. difficultly); How do you feel when you wake up in the morning? (1. refreshed, 2. rather refreshed, 3. neutral, 4. rather sleepy, 5. sleepy); Do you have enough time to sleep? (1. enough, 2. rather enough, 3. neutral, 4. rather deficient, 5. deficient); Do you sleep deeply? (1. deeply, 2. rather deeply, 3. neutral, 4. rather lightly, 5. lightly); Did you sleep well compared to the last week? (1. well, 2. rather well, 3. neutral, 4. rather badly, 5. badly).

Similarly, responses to a questionnaire regarding their bedding, clothing, and air conditioning were also recorded. A whole-body thermal sensation scale and the evaluation of thermal environment, a 9-point scale similar to that used by the Society of Heating, Air-conditioning, and Sanitary Engineers of Japan, was used − 9, very hot; 8, hot; 7, warm; 6, slightly warm; 5, neutral; 4, slightly cool; 3, cool; 2, cold; 1, very cold. A 7-point comfort sensation scale, similar to that used by the Japan Society of Refrigeration and Air-

conditioning Engineers, was also used − 1, very comfortable; 2, comfortable; 3, slightly comfortable; 4, neutral; 5, slightly uncomfortable; 6, uncomfortable; 7, very uncomfortable. Humidity was also assessed using a 7-point scale − 1, very dry; 2, dry; 3, slightly dry; 4, neutral; 5, slightly humid; 6, humid; 7, very humid.

2.3. Data analysis

Sleep parameters were determined using an actigraph-based, sleep-wake identification algorithm [13]. In order to test the statistical significance of the data, one-way analysis of variance (ANOVA) was used to analyze the effect of seasons (spring, summer, autumn and winter) on activity, sleep parameters, as well as thermal and lighting parameters. For each subject, the numbers of minutes of environmental illumination above 1000 lux were counted for each complete day of recording. The illumination values were log-transformed and used to calculate 50% of the cumulative or average illumination during the daytime and during the sleep period; the average illumination, 30-min before awakening, was also determined. Fisher's protected least significance difference (PLSD) was applied for post-hoc pair wise comparisons. A P-value <0.05 was considered statistically significant. To analyze the correlation between actigraphy-based sleep parameters, i.e., bedtime, sleep onset time, total time in bed, sleeping time, waking time after sleep onset, sleep efficiency index, awaking time, bedroom temperature and humidity during nocturnal sleep period, illuminance level during daytime, average and cumulative illuminance, and average illuminance for 4 h before sleep, during nocturnal sleeping period, and for 30 min before morning awaking, a Pearson's correlation matrix was used. The level of significance was considered to be $P < 0.05$.

3. Results

3.1. Lighting and thermal conditions

Table 1 summarizes the results of lighting environment investigated in four seasons. Sunrise was at 04:47 ± 0:11 h in spring, 04:45 ± 0:03 h in summer, 05:53 ± 0:03 h in autumn, and 06:41 ± 0:02 h in winter. Sunset also varied during the study period, depending on the season: spring (18:26 ± 0:09 h), summer (18:44 ± 0:03 h), autumn (16:53 ± 0:04 h), and winter (17:03 ± 0:04 h). As a result, the daylight hours were longer in the spring (13:39 ± 0:21) and summer (13:59 ± 0.06) than in the autumn (10:59 ± 0.08) and winter (10:21 ± 0:07).

Some of the subjects spent outdoor to work for 5.4 (2.7) hours in spring, 3.9 (2.1) hours in summer, 2.3 (2.9) hours in autumn, and 2.6 (2.7) hours in winter. Ambient lighting level was influenced by the time spent of outdoor. Significant seasonal variation was observed in the average [$F(3,28) = 4.71$; $P < 0.008$], cumulative [$F(3,28) = 4.55$; $P < 0.05$], and median [$F(3,28) = 6.10$; $P < 0.002$] illumination, number of minutes of illumination above 2500 lux [$F(3,28) = 3.51$; $P < 0.028$], and the average illumination 30-min before awakening in the morning [($F(3,28) = 2.46$; $P < 0.08$]. These values were significantly higher in spring than in summer, autumn, or winter.

Significant seasonal variation was also observed in the outside Ta [$F(3,60) = 340.10$; $P < 0.001$], bedroom temperatures [$F(3,60) = 240.64$; $P < 0.001$], as well as in the humidity levels [$F(3,60) = 203.41$; $P < 0.001$]. The average temperature and humidity were significantly higher in summer than in spring, autumn, or winter (Table 2). Average (SD) bedding insulation was 5.5 (1.9) clo in spring, 2.8 (0.8) clo in summer, 5.9 (1.7) clo in autumn, and 6.9 (1.5) clo in winter. There were no significant seasonal differences in the number of mattresses used [$F(3,60) = 0.45$; ns] or the clothing assessment values [$F(3,60) = 0.043$; ns]. However, the number of bed coverings and the clothing insulation values differed significantly among the seasons [$F(3,60) = 24.51$; $P < 0.0001$; $F(3,60) = 49.26$; $P < 0.0001$, respectively], i.e., a lower number of covers, with less insulating clothing, were used in summer than in spring and autumn, and in spring than that in winter. However, the clothing insulation in spring was not different from that in autumn.

3.2. Skin temperature and microclimate

Fig. 1 shows the mean Tsk, forehead Ts, and microclimate humidity during the sleep of the elderly people in the four seasons. Before the subjects started to sleep, the mean Tsk was different depending on the Ta in the bedroom during the four seasons. However, the mean skin temperature in all the seasons increased after the sleep started and converged at around 34.5 °C between 1 and 2 h after the sleep onset. Although no significant seasonal differences were found in the mean Tsk values [$F(3,22) = 1.8$, $P = 0.1767$] during the sleep periods, the mean Tsk in summer season was lower than those in the other seasons. Significant seasonal differences were found for the Tsk of the forehead [$F(3,22) = 11.099$, $P = 0.0001$] and chest [$F(3,22) = 4.448$, $P = 0.0138$]. The forehead Tsk values were significantly higher in spring and summer than in autumn and winter, and the average chest Tsk was significantly lower in summer than in winter because

Table 1
Lighting environments during a whole day and sleep period.

Season	Spring	Summer	Autumn	Winter
Cumulated illuminance (Lx h)*	989 (589)[b,c,d]	546 (307)[a]	371 (379)[a]	278 (162)[a]
Average (lx)*	16.5 (9.8)[b,c,d]	9.1 (5.1)[a]	6.2 (6.3)[a]	4.6 (2.7)[a]
Median (lx)**	19.8 (13.7)[b,c,d]	9.7 (6.2)[a]	5.7 (4.8)[a]	3.3 (2.2)[a]
Minutes of illuminance above 2500 lux (min)**	133.8 (92.3)[b,c,d]	48.9 (33.1)[a]	46.6 (60.7)[a]	47.1 (39.3)[a]
Minutes of illuminance above 1000 lux (min)	180.4 (100.8)	100.4 (55.2)	72.6 (65.6)	63.6 (56.3)
Average during daytime (lx)*	124.8 (114.2)[b,c,d]	41.2 (23.3)[a]	41.1 (63.9)[a]	28 (22.7)[a]
Average during sleeping period (lx)	1 (1.8)	1.5 (2.8)	1.4 (2.7)	2.1 (3.8)
average of 30-min before morning awake (lx)	2.8 (5)[b,d]	20.2 (49.5)[a]	4.6 (8.3)	1.6 (3.6)[a]

Values are average (SD).
*,**shows main effect of season at $P < 0.01$, $P < 0.05$, respectively.
[a] Differs from Spring, $P < 0.05$.
[b] Differs from Summer, $P < 0.05$.
[c] Differs from Autumn, $P < 0.05$.
[d] Differs from Winter, $P < 0.05$.

Table 2
Average indoor thermal environment and skin temperature of the elderly people during the sleep.

Season	Spring	Summer	Autumn	Winter
Outdoor ta (°C) **	18 (1.8)[b,c,d]	24.9 (1.0)[a,c,d]	12.4 (3.6)[a,b,d]	0.4 (1.1)[a,b,c]
Bedroom ta (°C)**	22.5 (1.4)[b,c,d]	27.8 (1.0)[a,c,d]	18.4 (1.8)[a,b,d]	10.3 (2.6)[a,b,c]
Bedroom rh (%)	64.8 (7.5)	72.6 (7.4)	69.8 (6.7)	59.4 (5.9)
Bedroom humidity (Torr)**	13.2 (0.4)[b,c,d]	20.3 (0.4)[a,c,d]	11.1 (0.3)[a,b,d]	5.6 (0.3)[a,b,c]
Toilet ta (°C)**	21.4 (1.4)[b,c,d]	27.5 (1.0)[a,c,d]	16.9 (3.1)[a,b,d]	7.3 (2.4)[a,b,c]

Values are average (SD).
**shows main effect of season at $P < 0.01$.
[a] Differs from Spring, $P < 0.05$.
[c] Differs from Autumn, $P < 0.05$.
[b] Differs from Summer, $P < 0.05$.
[d] Differs from Winter, $P < 0.05$.

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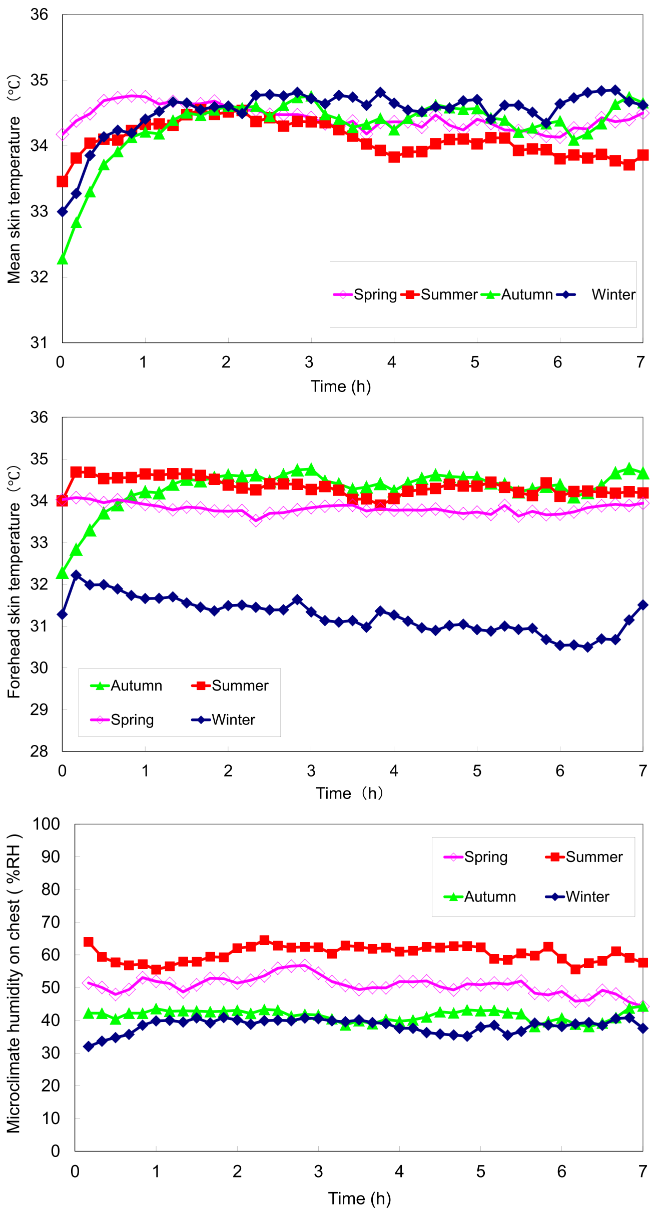

Fig. 1. Changes in mean skin temperature, forehead skin temperature, and microclimate humidity in the chest during the sleep period.

the head was out of the bedding and the forehead Tsk was influenced directly by the ambient Ta. The chest Tsk was also affected by the ambient Ta or bedding because the chest area was covered by the thick bedding in the winter season but uncovered and exposed to the ambient air through thinner pajama in the summer season. No significant seasonal differences were found in the local Tsk values of the upper arm [$F(3,22) = 2.758$], thigh [$F(3,22) = 0.782$], calf [$F(3,22) = 1.454$], and foot [$F(3,22) = 1.126$].

The microclimate humidity between the pajamas and chest skin was significantly higher in spring and summer than in autumn and winter, and in summer than in spring. Significant seasonal differences were found in the microclimate humidity of the chest [$F(3,21) = 18.37$, $p < 0.0001$], however, not in the microclimate temperature [$F(3,23) = 0.906$, $P = 0.4533$]. Significant seasonal differences were found in the microclimate humidity under the pajamas [$F(3,21) = 9.487$, $P = 0.0004$] and the microclimate temperature of the foot [$F(3,22) = 3.403$, $p = 0.0356$]. The foot microclimate temperature was significantly higher in spring and winter than in summer. This might be also due to bedding used in spring and winter seasons.

3.3. Sleep parameters

Based on wrist activity, significant differences in sleep parameters were observed between summer and other seasons (Table 3). There was no significant difference in the amount of time spent in bed [$F(3,60) = 0.96$], whereas the wake-up times [$F(3,60) = 3.35$; $P < 0.05$] in spring and summer were significantly earlier than in winter. There were no significant differences in sleep latency [$F(3,60) = 0.30$], time spent lying down [$F(3,60) = 0.55$], or total sleep time [$F(3,60) = 1.40$] among the different seasons; however, the awake time [$F(3,60) = 3.70$, $P < 0.05$], in summer, was significantly longer than in spring, autumn, or winter. The number of waking episodes during sleep [$F(3,60) = 2.24$, $P < 0.1$] was significantly higher in summer than in winter. Compared with spring, autumn, and winter, the sleep efficiency index [$F(3,60) = 3.15$; $P < 0.05$] was significantly lower (by 5%) in summer. The total activity [$F(3,60) = 4.43$; $P < 0.007$] was higher in summer than in the other seasons. No significant seasonal differences were observed with regard to the total activity and length of daytime sleep.

We tried to find correlations between the sleep parameters and environmental factors such as temperature, humidity, and illuminance levels measured at the same time as already described. Table 4 shows the coefficient of correlations between the sleep parameters and environmental factors. Bedtime and wake-up time had good correlations with lighting level for 4 h before going to bed. Bedtime was delayed with increased lighting level, however, wake–up time became earlier in accordance with increased lighting level as well as increased ta and humidity in the bedroom. Sleep latency had no correlation with any lighting and thermal environmental factors. However, sleeping time increased in accordance with increased lighting level during daytime, moreover, decreased as well as increased lighting level before sleep or increased ambient ta and humidity during sleeping period. Wake time after sleep onset increased with increased lighting level before sleep as well as

Table 3
Sleep parameters.

Season	Spring	Summer	Autumn	Winter
Period	Apr 19–May 14	Jul 26–Aug 6	Oct 18–29	Jan 24–Feb 4
Sunset time (h:m)	18:25	18:46	16:44	17:02
Sunrise time (h:m)	4:46	4:43	5:59	6:41
Night time				
Bedtime (h:m)	22:31 (1:17)	22:35 (0:57)	22:35 (0:43)	22:51 (0:55)
Wake-up time (h:m)	5:41 (1:07)[d]	5:58 (0:37)[d]	6:09 (0: 34)	6:30 (0:32)[a,b]
Time in bed (min)	431.2 (100.8)	443.9 (56.2)	455.3 (51.6)	460.3 (59.0)
Total sleep time (min)	381.8 (96.3)	366.4 (61.2)	405.5 (57.9)	412.1 (64.0)
Wake (min)	49.4 (25.3)[b]	77.5 (45.6)[a,c,d]	49.8 (18.7)[b]	48.3 (20.2)[b]
Sleep efficiency index (%)	88.3 (5.9)[b]	82.7 (10.4)[a,c,d]	88.9 (4.7)[b]	89.3 (5.5)[b]
Sleep latency (min)	15.3 (22.8)	19.3 (16.7)	13.8 (11.0)	16.3 (14.6)
Number of wake episode	9.3 (5.0)	12.3 (8.6)[d]	8.7 (3.5)	7.4 (3.4)[b]
Longest wake episode (min)	21.1 (14.4)	29.5 (19.6)	19.8 (5.2)	22.9 (15.5)
Activity index	17.2 (7.0)[b]	25.5 (12.8)[a,c,d]	17.1[b]	16.1 (6.3)[b]
Daytime				
Activity index	207.5 (34.5)	199.8 (35.1)	170.4 (42.6)	185 (55.7)
Sleep time (min)	36.6 (50.5)	30.1 (39.9)	86.1 (70.2)	18.2 (25.9)

Values are average (SD).
[a] Differs from Spring, $P < 0.05$.
[b] Differs from Summer, $P < 0.05$.
[c] Differs from Autumn, $P < 0.05$.
[d] Differs from Winter, $P < 0.05$.

Table 4
Correlation matrix of sleep parameters and lighting and thermal environmental factors.

	Bedtime	Wake-up time	SL	SPT	WASO	SEI
Maximum lighting during daytime	NS	NS	NS	NS	NS	NS
Cumulative ligting during daytime	NS	NS	NS	NS	NS	NS
Minutes of lighting above 1000 lux	NS	NS	NS	0.231*	NS	NS
Average lighting during daytime	NS	NS	NS	0.267*	NS	NS
Average lighting during 4-h before sleep	0.198*	−0.294*	NS	0.188*	0.22**	NS
Average lighting during sleep	NS	NS	NS	−0.31**	0.187*	−0.292**
Lighting during 30-min before morning awake	NS	NS	NS	NS	NS	−0.337**
Bedroom ta during sleep	NS	−0.517**	NS	−0.351**	0.266*	−0.383**
Bedroom humidity during sleep	NS	−0.468**	NS	−0.361**	0.226*	−0.336**
Activity accounts during daytime	NS	−0.231*	NS	NS	0.213*	NS

** < 0.01, * <0.05.
SL: Sleep latency.
SPT: Sleeping time.
WASO: Wake time after sleep onset.
SEI: Sleep Efficiency Index.

increased lighting, ta, and humidity during sleep period. Sleep efficiency index also reduced with increase lighting, ta, and humidity during sleep. The activity accounts during the daytime measured by actigraphy were cumulative and analyzed. Activity log by self−reported behavior or activity were estimated following the ISO 8996 [14]. However, no significant difference was found in the activity accounts and self -reported activity between the seasons.

3.4. Subjective sensation

Table 5 shows the subjective evaluations of sleep in each season and the thermal comfort sensations before and during the sleep period. Average values of 5 questions for the subjective evaluations of sleep were mostly less than 3, which mean better subjective evaluations because the 3 means neutral and smaller number is better. Significant differences were not observed in the subjective evaluations of sleep among the four seasons.

Before sleep, the subjects reported to feel warmer in spring than in autumn; however, no difference was found in the comfort sensations among the four seasons. Most of the participants wanted no change in Ta and humidity before the sleep.

When the subjects awakened, they were asked to fill out a questionnaire on the retrospective impression of their sleep and thermal comfort during the sleep. Whole-body thermal sensation showed a significant difference [$F(3,53) = 3.136$, $P = 0.0329$]. The volunteers felt significantly warmer during summer than during winter and autumn. Regarding retrospective sensations during sleep, a significant effect of the seasons was observed on the humidity sensation [$F(3,60) = 4.33$; $P < 0.007$], whole body thermal sensation [$F(3,60) = 4.33$; $P < 0.0078$], leg thermal sensation [$F(3,60) = 1.70$; ns], comfort sensation [$F(3,60) = 4.70$, $P = 0.005$], and the requirement for changing the Ta [$F(3,60) = 4.35$; $P < 0.007$] and humidity [$F(3,60) = 5.93$; $P < 0.0013$]. Whole-body thermal sensation was significantly higher in spring than in summer, autumn, or winter. The comfort sensation was significantly higher in autumn than in spring, summer, or winter. The humidity sensation was higher, the whole-body and leg thermal sensations were lower, and the requirements for decreasing the Ta and humidity were higher in summer than in autumn and winter.

The relationships between the bedroom ambient Ta and the retrospective thermal sensations are shown in Fig. 2. In summer, a strong correlation was observed between the ambient Ta and

Table 5
Subjective evaluations for the sleep and thermal comfort sensations.

	Spring	Summer	Autumn	Winter
Subjective sleepiness				
Do you fall asleep easily?	2.4 (1.4)	2.7 (1.4)	2.1 (0.9)	2.3 (1.1)
How do you feel when you wake up in the morning?	2.6 (0.5)	2.4 (0.8)	2.3 (0.9)	2.4 (0.8)
Do you have enough time to sleep?	2.5 (1.2)	2.4 (1.1)	2.1 (0.9)	2.3 (1.1)
How do you sleep deeply?	2.5 (0.8)	2.8 (1)	2.6 (0.6)	2.7 (0.8)
Do you sleep well compared to the last week?	3.1 (0.7)	2.7 (1.1)	2.6 (0.8)	3.1 (0.6)
Thermal comfort				
BEFORE SLEEP				
Thermal sensation of whole body	5.6 (0.5)[c]	5.4 (1.5)	4.9 (0.7)[a]	5.4 (0.5)
Thermal sensation of foot	5.7 (0.5)[c]	5.4 (0.8)	5 (0.7)[a]	5.5 (0.8)
Comfort sensation	3.6 (0.7)	3.9 (0.7)	3.8 (0.6)	3.9 (0.3)
Feeling of Sweating	1.2 (0.4)	1.4 (0.5)[c,d]	1.1 (0.3)[b]	1.1 (0.3)[b]
Requirement for changing ta	3.9 (0.3)	3.8 (0.4)[c,d]	4.1 (0.3)[b]	4 (0.4)
Requirement for changing humidity	3.9 (0.3)[d]	3.8 (0.6)[c,d]	4.1 (0.3)[b]	4.2 (0.4)[a,b]
RETROSPECTIVE SENSATIONS DURING SLEEP				
Thermal sensation of whole body	6.6 (0.9)[b,c,d]	5.4 (1.2)[a]	5.4 (1.1)[a]	5.8 (0.8)[a,b]
Thermal sensation of foot	5.9 (0.9)	5.4 (0.8)	5.4 (0.8)	5.7 (0.8)
Comfort sensation	3.9 (0.7)[c]	4.1 (0.9)[c,d]	3.3 (0.8)[a,b,d]	3.9 (0.3)[c]
Feeling of Sweating	1.4 (0.6)[c,d]	1.6 (0.9)[c,d]	1.0 (0.0)[a]	1.0 (0.0)[a,b]
Requirement for changing ta	3.8 (0.4)	3.7 (0.5)[c,d]	4.1 (0.3)[b]	4.1 (0.3)[b]
Requirement for changing humidity	3.8 (0.4)[c,d]	3.6 (0.5)[c,d]	4.1 (0.3)[a,b,d]	4.1 (0.3)[a,b]

[a] Differs from Spring, $P < 0.05$.
[b] Differs from Summer, $P < 0.05$.
[c] Differs from Autumn, $P < 0.05$.
[d] Differs from Winter, $P < 0.05$.

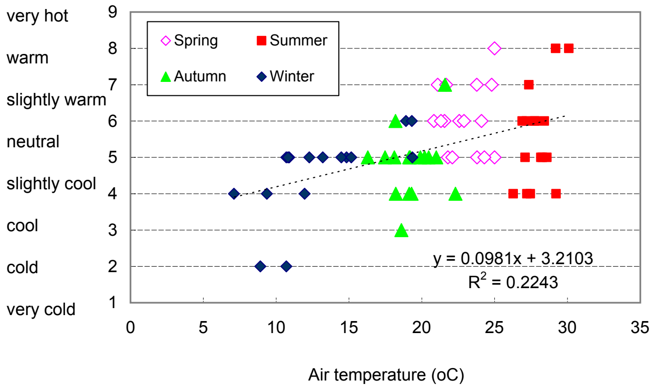

Fig. 2. Relationship between the air temperature and retrospective evaluation for the thermal environment during the sleep period.

thermal sensation and a weak correlation between Ta and thermal sensations were found in the other seasons, depending on the Ta. The correlation between mean Tsk and thermal sensation is not illustrated, however, no difference was found among sleeping subjects because they did not use much covering in the summer season, or mostly covered their abdomen only with thinner bedding or towel. Tsk was maintained during the sleeping period and thermal sensations were evaluated not in the whole body, but specifically in the face or other local parts of the body that were exposed to ambient air.

4. Discussion

The most remarkable finding from this study was that the waking period illumination was highest in the spring. In particular, the percentage or length of time that the illumination was >1000 lux was significantly higher in spring than in the other seasons; there were no differences in the other lighting parameters for summer, autumn, and winter because the subjects spent outdoor in the spring season. We presumed that daylight had an effect on the subsequent nocturnal sleep among the elderly in summer; however; large differences in lighting were not found between summer and the other seasons, except for the amount of light at the time of the morning awakening. On the contrary, in the previous study comparing ambient illuminance level between older and young counterparts, older subjects got higher level of light exposure compared to young subjects in summer and autumn compared to other seasons [8]. This difference was due to the latitude of the locations where the investigation was conducted. However, average light level in the older subjects in the previous study was almost similar to this study.

The amount of light during the morning awakening was significantly higher in summer than in spring or winter. The amount of light at the morning awakening might be associated with the wake-up time; however, the summer wake-up time was not significantly different from that in spring. Moreover, correlation with sleep parameters was investigated for the nocturnal lighting and thermal parameters during the sleep period or daylight, and behavioral activity accounts during the waking period, and no significant correlation was found. The neurophysiologic mechanisms mediating nocturnal light is known to impair the sleep onset by suppressing melatonin secretion [15,16]. Epidemic studies recently showed that the evening light prior to sleep prolongs subsequent sleep onset latency in the elderly [17]. Moreover, nocturnal light during the night period showed impairment of sleep through subjectively and objectively measuring sleep, although, no difference was found in the urinary 6-sulfatoxymelatonin excretion [18]. In this study, we did not collect urine samples for measuring melatonin secretion during the night. Thus, we could not confirm any effects of the amount of spring light on sleep. However, in a previous cross-sectional study, the relationship between environmental lighting and urinary 6-sulfatoxymelatonin excretion was examined in an uncontrolled, daily life setting. In that study, daylight exposure was positively associated with urinary melatonin excretion in the elderly [9]. The levels of ambient illumination and daytime activity might induce a good nocturnal sleep in the elderly; appropriate springtime Ta and RH might also be beneficial since the subjects reported nocturnal wakefulness due to elevated temperatures.

The wakefulness and activity during sleep significantly increased, and the sleep efficiency index significantly decreased in summer compared with spring, autumn, or winter; there were no significant differences in these measures between spring, autumn, and winter. Moreover, there were no differences in bedtime, time in bed, total sleep time, and sleep latency among the 4 seasons. The results of the present study suggest that sleep quality was worst in summer, supporting the results of our previous study [10]. The reason for this may be explained by the heat load because typical effects of heat exposure situations increase wakefulness [19–21]. This study also confirmed the effect of heat load on the elderly during sleep in the summer season.

The wake-up time was earliest in spring, but there was no significant difference in the bedtime among the 4 seasons. The time in bed was the shortest, but non-significant, in spring, and the total sleep and awake times were not significantly different among the 4 seasons. This difference in spring might be due to higher illumination level. Moreover, the retrospective subjective wakefulness due to heat was significantly affected by the seasons. Elderly people felt that their subjective wakefulness, during sleep periods, was greater in spring and summer than in autumn and winter. However, the amount of time that the subjects were awake did not increase as much in spring as it did in summer, based on actigraphy measurements. Even though the elderly volunteers spontaneously awoke at midnight, due to the elevated temperature in spring, they were able to go back to sleep quickly. The ability to sleep in spring might be associated with the amount of daytime illumination.

Ambient thermal parameters were significantly different among the 4 seasons. The indoor temperature and humidity were highest in summer, with progressively lower values experienced in spring, autumn, and winter. The reason that sleep quality was poorest in the summer season was previously explained as being the result of fluctuations in Tsk [10]. The fluctuations resulted due to the forehead Tsk increasing because of the heat load in summer compared with autumn and winter, whereas the chest and thigh temperatures decreased due to reduced amounts of bedding. However, in the present study, there were no significant differences in the chest, upper arm, thigh, calf, and mean Tsk values among the 4 seasons; forehead Tsk values showed significant differences that were dependent on and well correlated with the Ta. Moreover, the microclimate humidity, in the region between the chest skin and pajamas, was significantly higher in summer than in the other seasons. This elevated microclimate humidity was thought to be the result of increased sweating, which may also contribute to poor sleep quality in summer. Sweating, which is a thermoregulatory mechanism, has previously been suggested to result in a significantly higher degree of nocturnal wakefulness [20–23]. This result has been supported by observations that thermal load is increased during summer, with increased wakefulness being a typical result of increased heat exposure [20,24]. In a previous experimental study, a Ta of 32 °C increased wakefulness

and suppressed REM in older men [25]. Although, the Ta of 28 °C in this study was lower than that reported in the previous study, wakefulness was still significantly increased. One reason for this may have been the higher humidity (>70% RH); humid heat increases sweating during sleep by suppressing SWS and REM and increases wakefulness [23].

Definite seasonal differences were found in the bedroom Ta and the extent of insulation provided by the bedding and pajamas, despite a lack of seasonal differences in the mean Tsk (34 °C) over the 4 seasons. The selection of bedding and clothing may be appropriate for the ambient environment in each season, resulting in a lack of correlation between the mean Tsk and thermal sensation during sleep. In winter, the subjects in this study were exposed to acute Ta changes of <10 °C from the bedding climate (approximately 32 °C), since most subjects awoke to use the lavatory during the night. However, the subjects did not require any additional time to fall asleep again, upon returning to bed in winter than in other seasons. Such acute Ta changes affect thermoregulation and cardiovascular responses, especially increasing blood pressure, in elderly men [26,27] and may also relate to cardiac disease, but we did not observe any such effects on the human body during this study. During the sleep period, the mean Tsk was almost similar in all 4 seasons, however, the ambient Ta was highest in summer, such that a small temperature difference restrains the heat loss and induces sweating. The higher microclimate humidity inside the pajama diminished the sleep quality [24].

Previous epidemiologic research have shown that women have more sleep onset complains than men and that elderly women reported poor quality of sleep, however, actigraphic sleep measurements showed poorer sleep in men [28]. Another epidemiologic data also showed a consistent association between gender and actigraphic sleep onset latency in elderly people in Japan [18]. In our previous study, the male subjects showed lower sleep efficiency index than woman subjects. Therefore, in this study, we measured the effect of lighting data on the sleep as well as thermal environment at the same time. Our measurement of lighting data was not enough to evaluate the effect of light on sleep or circadian rhythms. However, the correlations between the sleep parameters and environmental factors such as temperature, humidity, and illuminance levels measured at the same time showed that increased lighting level before the sleep prolongs the bedtime and wake time after sleep onset, and became earlier wake-up time. Increased ta, humidity, and lighting level during the sleep period increased wake time after sleep onset and impaired the sleep quality.

5. Conclusion

Bedroom nocturnal Ta and humidity were significantly higher in summer and daytime illumination was significantly higher in spring than in the other seasons. Sleep efficiency was worst in summer due to the increased number and duration of nocturnal awakenings. However, a significant difference was not found in the subjective evaluation of sleep among the 4 seasons. The subjects felt warmer and reported more subjective wakefulness in spring than in the other seasons; however, their sleep quality was not diminished. The correlations between the sleep parameters and environmental factors such as temperature, humidity, and illuminance levels measured at the same time showed that increased lighting level before the sleep prolongs the bedtime and wake time after sleep onset, and became earlier wake-up time. Increased ta, humidity, and lighting level during the sleep period increased wake time after sleep onset and impaired the sleep quality.

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References

[1] Kohsaka M, Fukuda N, Honma K, Honma S, Morita N. Seasonality in human sleep. Experientia 1992;48:231–3.
[2] Askenasy JJ, Goldstein R. Does a subtropical climate imply a seasonal rhythm in REM sleep? Sleep 1995;18:895–900.
[3] Herer P, Lavie P. Nonreplicability of seasonal rhythm in REM sleep in a subtropical climate. Sleep 1997;20(5):359–61.
[4] Monk TH. Sleep and circadian rhythms. Exp Gerontol 1991;26:233–43.
[5] Monk TH, Reynolds CF, Buysse DJ, Hoch CC, Jarrett DB, Jennings JR, et al. Circadian characteristics of healthy 80-year-olds and their relationship to objectively recorded sleep. J Gerontol 1991;46:M171–5.
[6] Dorsey CM, Teicher MH, Cohen-Zion M, Stefanovic L, Satlin A, Tartarini W, et al. Core body temperature and sleep of older female insomniacs before and after passive body heating. Sleep 1999;22:891–8.
[7] Mishima K, Okawa M, Shimizu T, Hishikawa Y. Diminished melatonin secretion in the elderly caused by insufficient environmental illumination. J Clin Endocrinol Metab 2001;86:129–34.
[8] Scheuermaier K, Laffan AM, Duffy JF. Light exposure patterns in healthy older and young adults. J Biol Rhythms 2010;25(2):113–22.
[9] Obayashi K, Saeki K, Iwamoto J, Okamoto N, Tomioka K, Nezu S, et al. Exposure to light at night, nocturnal urinary melatonin excretion, and obesity/dyslipidemia in the elderly: a cross-sectional analysis of the HEIJO-KYO study. J Clin Endocrinol Metab 2013;98(1):337–44.
[10] Okamoto-Mizuno K, Tsuzuki K. Effects of season on sleep and skin temperature in the elderly. Int J Biometeorol 2010;54(4):401–9.
[11] Horne JA, Ostberg O. A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. Int J Chronobiol 1976;4:97–110.
[12] Cole R, Kripke D, Gruen W, Mullaney D, Gillin J. Automatic sleep/wake identification from wrist activity. Sleep 1992;15:461–9.
[13] Ramanathan NL. A new weighting system for mean surface temperature of the human body. J Appl Physiol 1964;19:531–3.
[14] ISO8996. Ergonomics – determination of metabolic heat production. 2004.
[15] Dijk DJ, Cajochen C. Melatonin and the circadian regulation of sleep initiation, consolidation, structure, and the sleep EEG. J Biol Rhythms 1997;12:627–35.
[16] Zeitzer JM, Dijk Derk-Jan, Kronauer Richard E, Brown Emery N, Czeislerl Charles A. Sensitivity of the human circadian pacemaker to nocturnal light: melatonin phase resetting and suppression. J Physiol 2000;526:695–702.
[17] Kenji Obayashi, Saeki Keigo, Iwamoto Junko, Okamoto Nozomi, Tomioka Kimiko, Nezu Satoko, et al. Effect of exposure to evening light on sleep initiation in the elderly – a longitudinal analysis for repeated measurements in home settings. Chronobiol Int 2014;31(4):461–7.
[18] Kenji Obayashi, Saeki Keigo, Kurumatani Norio. Association between light exposure at night and insomnia in the general elderly population: the HEIJO-KYO cohort. Chronobiol Int 2014. Early Online: 1–7.
[19] Karacan I, Thornby JI, Anch AM, Williams RL, Perkins HM. Effects of high ambient temperature on sleep in young men. Aviat Space Environ Med 1978;49:855–60.
[20] Haskell EH, Palca JW, Walker JM, Berger RJ, Heller HC. The effects of high and low ambient temperatures on human sleep stages. Electroencephalogr Clin Neurophysiol 1981;51:494–501.
[21] Libert JP, Di Nisi J, Fukuda H, Nuzet A, Ehrhart J, Amoros C. Effect of continuous heat exposure on sleep stages in humans. Sleep 1988;11(2):195–209.
[22] Parmeggiani PL. Interaction between sleep and thermoregulation: an aspect of the control of behavioral states. Sleep 1987;10:426–35.
[23] Okamoto-Mizuno K, Mizuno K, Michie S, Maeda A, Iizuka S. Effects of humid heat exposure on human sleep stages and body temperature. Sleep 1999;22:767–73.
[24] Tsuzuki K, Okamoto-Mizuno K, Mizuno K. Effects of humid heat exposure on sleep, thermoregulation, melatonin, and microclimate. J Therm Biol 2004;29:31–6.
[25] Okamoto-Mizuno K, Tsuzuki K, Mizuno K. Effects of mild heat exposure on sleep stages and body temperature in older men. Int J Biometeorol 2004;49(1):32–6.
[26] Inoue Y, Nakao M, Araki T, Murakami H. Regional differences in the sweating responses of older and younger men. J Appl Physiol 1991;71:2453–9.
[27] Collins KJ, Abdel-Rahman TA, Goodwin J, McTiffin L. Circadian body temperatures and the effects of a cold stress in elderly and young subjects. Age Ageing 1995;24:485–9.
[28] van den Berg JF, Miedema HM, Tulen JH, Hofman Alber, neven Arie Knuistingh, Temeier Henning. Sex differences in subjective and actigraphic sleep measures: a population-based study of elderly persons. Sleep 2009;32:1367–75.